Thermal Treatment of Sewage Sludge – Pyrobustor

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1. Introduction

Sewage sludge is a side product of municipal and industrial waste water treatment plants, which although being rich in nutrients is difficult to be disposed of due to its content of pollutants.

The recycling of the nutrients contained in the sewage sludge as fertilizers became controversial with the beginning of the ‘80s, when soil contamination due to the heavy metals, dioxins, furanes and germs content started to be subject of debate. Thus many countries reduced, or in some cases completely renounced on the usage of sewage sludge in agriculture in order to reduce soil pollution and the consequently involved food chain contamination/ health risks.

The most often practiced sewage sludge disposal way is still being landfilling, even though sewage sludge, due to its physical properties is the least suitable for dumping and from the ecological point of view landfilling is the most harmful elimination procedure on long terms.

Since 2005, according to the regulation *TA Siedlungsabfall* only dewatered or thermally pre-treated sewage sludge may be landfilled.

As optional solutions biological and thermal disposal processes are available. The biological processes (composting) require considerable space and time, are less effective regarding volume reduction and generate end products that are still contaminated with pollutants.

The thermal treatment of sewage sludge has a high efficiency regarding volume as well as mass reduction, while converting the toxic compounds into harmless substances in the thermal process. As thermal treatment the mono-incineration of sewage sludge is an established technology in the fluidized bed, just as the co-combustion in the cement industry. In case of co-combustion the less severe emission limits of the cement industry are applying, while when sewage sludge is mono-incinerated it must be complied with the more stringent emission limits of waste incineration.

However, these centralized thermal solutions are cost-effective only for bigger waste water treatment plants located in the vicinity of the thermal treatment facility. The increased logistic costs for less favourably located waste water treatment plants made the development of a decentralized solution necessary.

Eisenmann developed the so called Pyrobustor technology as a decentralized solution, which processes pre-dried sewage sludge in smaller amounts still being economically and energetically attractive.

2. Theoretical considerates regarding the thermal treatment of sewage sludge by the Pyrobustor technology

The Pyrobustor is a thermal treatment unit especially developed for the processing of middle caloric input substances. The Pyrobustor was born from the desire of developing a technology that can handle small throughput amounts while still being attractive from the point of view of investment as well as operation costs.

As already suggested by the name, the Pyrobustor is embracing two thermal treatment processes, the pyrolysis and the combustion. The graph below explains the build-up of the wording.

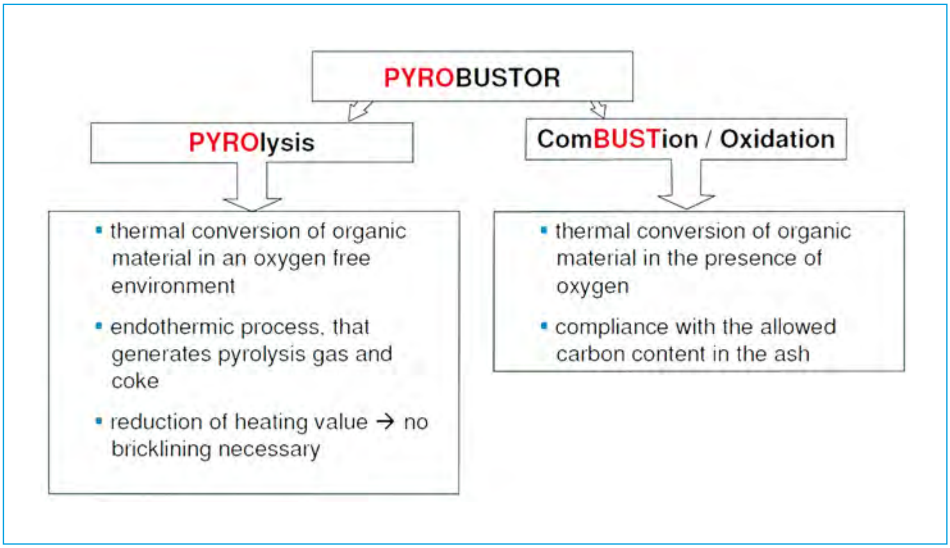

Figure 1: Explanation of the wording Pyrobustor

The Pyrobustor is a dual-chamber rotary kiln without brick lining in which the processes of pyrolysis and oxidation take place consecutively. The two processes occur in two separate drums, connected together and rotated synchronously. In the pyrolysis chamber, in an oxygen poor environment, the sewage sludge entering the combustion treatment undergoes at first a drying process, where the water is evaporated, followed by a low temperature pyrolysis (300-350 °C) of the dry matter, where pyrolysis coke and pyrolysis gas are generated.

Inside both drums, conveying and mixing blades in the form of a screw continuously transport the material to be treated.

Thus, the generated coke is transported from the pyrolysis chamber into the oxidation chamber, where in oxygen rich environment the remaining organic content of the coke is fully oxidized.

The pyrolysis gases generated in the pyrolysis chamber pass the oxidation chamber through a pipe located in the middle of the oxidation drum. Being given that the oxidation is an exothermal process, the pyrolysis gases are heated up and long chained carbohydrates are partially cracked, thus condensation of tars is avoided. The so heated up pyrolysis gases can be transported to the post combustion chamber without having blocking due to condensation products.

The gases produced in the oxidation chamber by the incineration of the pyrolysis coke are directed further on through the jacket of the pyrolysis chamber, where the endothermy of the pyrolysis process is covered by the energy content of these oxidation gases. Composition, heating value variations of the input material that influence negatively the energy balance are balanced out by a small burner installed at the outlet from the oxidation chamber in the oxidation gases pipeline.

For better exemplification, the picture below shows the schematic configuration of the Pyrobustor.

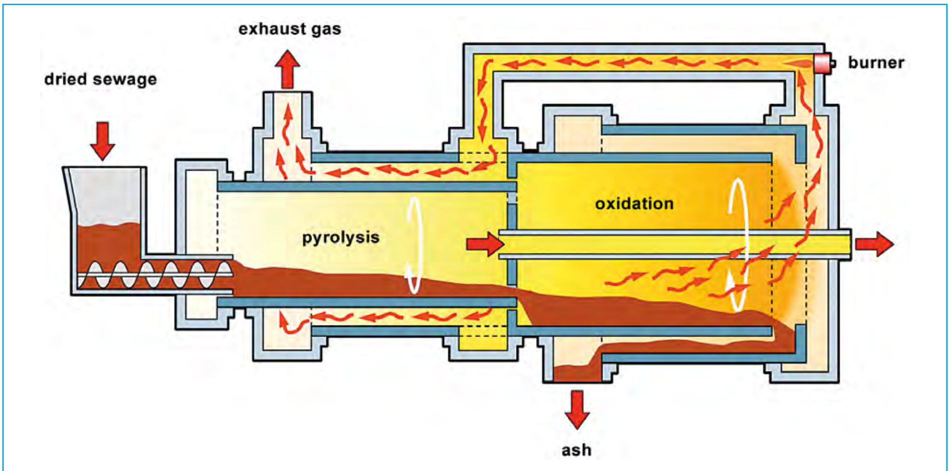

Figure 2: Schematic representation of the Pyrobustor incineration unit

The division of the incineration process into the two separate processes, pyrolysis and oxidation, leads to decreased temperatures in the oxidation zone, thus the Pyrobustor can be carried out as a full steel construction.

The adiabatic incineration temperature of dried sewage sludge lies above 1,000 °C, which would make the installation of brick inlining mandatory in the oxidation zone or the temperature would have to be adjusted by excess air, which would increase the amount of generated exhaust gases and directly increase as well investment, as well as operational costs. By realizing the thermal treatment in two steps, the calorific value of the dried sewage sludge is divided between pyrolysis gas and coke in the pyrolysis chamber which means the generation of a pyrolysis gas with a higher calorific value than the dried sludge and a pyrolysis coke with a lower calorific value than the dried sludge. Only the pyrolysis coke being directed into the combustion chamber, the oxidation process generates lower temperatures compared with the oxidation of dried sludge, so that no bricklining is necessary. Bricklining being a significant factor regarding investment costs, the solution´s advantages become obvious from the financial point of view.

The backflow of oxidation gases from the combustion chamber into the pyrolysis chamber is prevented by the adjustment of the local pressure conditions in the two chambers. By running the Pyrobustor under a slight vacuum it is assured that the gases flow exclusively in the direction of exhaust gas treatment and no oxygen rich gases come in contact with the pyrolysis gases in the Pyrobustor unit.

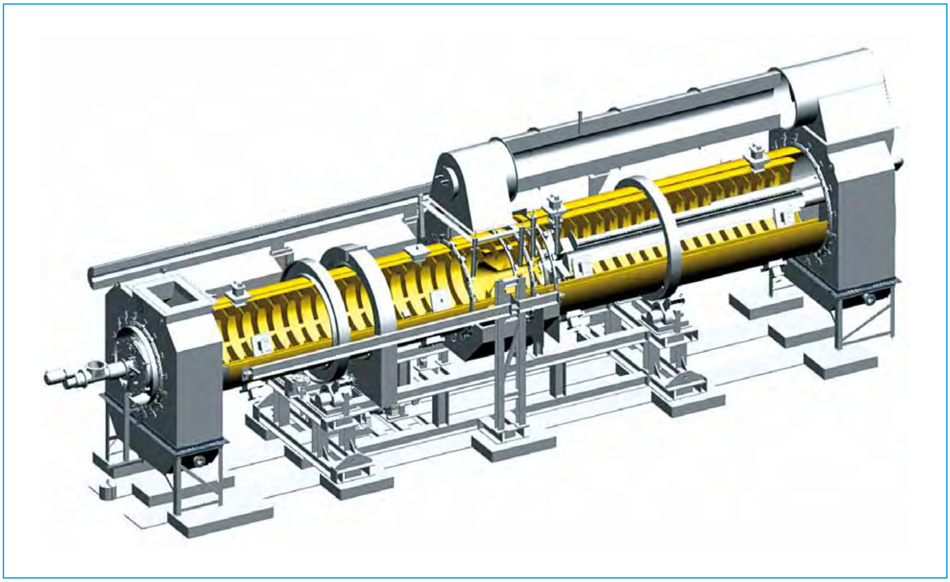

Figure 3: Constructive build-up of the Pyrobustor

The produced ash is transported to the ash discharge, giving part of its heat energy to the combustion chamber at the same time. Further on the ash is transported by the means of a screw conveyor to an intermediate storage tank and can be disposed of at a waste site, since it fulfills the requirements of landfilling (Landfill class 1, rest organic < 3 % DM).

In order to comply with the emission regulations the exhaust gases are directed to the post combustion chamber, where at a temperature of at least 850 °C and a minimum residence time of 2 seconds the complete oxidation of the organic content of the gases is assured. The energy demand for the post combustion is covered by the energy content of the pyrolysis gases.

The sewage sludge dried to 10 % water content is transported to the collection bin of the Pyrobustor by means of a screw conveyor. The collection bin is equipped with weighting cells in order to record the material input into the Pyrobustor.

As described above, the sewage sludge is splitted into pyrolysis gas and coke in the pyrolysis chamber. The coke will be then transported to the combustion drum to an oxygen rich environment.

The dimensions of the two drums cannot be varied during operation. In case of varying water content of the fed sewage sludge the retention time cannot be modified accordingly. The scenario, where the fed sewage sludge has a lower dry matter content as considered for the design of the Pyrobustor, would lead to insufficient retention time in the pyrolysis zone, thus the generated coke's heating value would be higher, which could lead to elevated temperatures in the oxidation zone with direct impact on the thermal stability of the steel construction.

The desired dry matter content of the fed sewage sludge can be adjusted by applying an additional drying system after the conventional centrifuge, for example a belt dryer, that can reduce the water content of the sludge to the required value. The energy demand of the dryer can be covered by the energy exploited from the flue gases leaving the post combustion chamber. Thus, the energy circle is closed. The picture below shows the build-up of an existing plant that processes successfully since 2005 sewage sludge with the Eisenmann Pyrobustor technology.

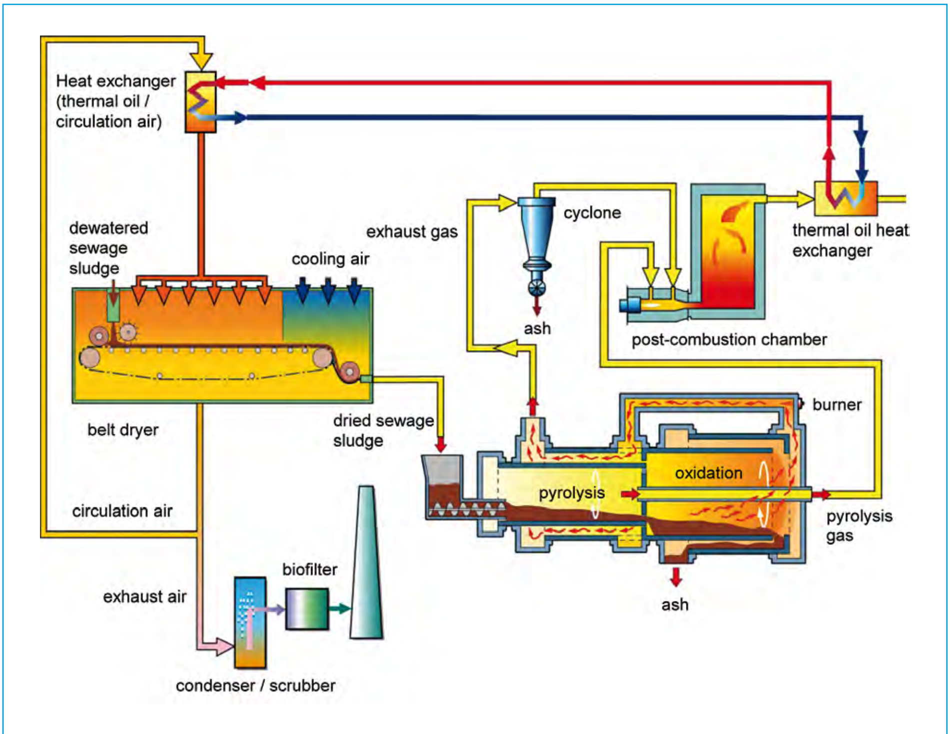

Figure 4: Simplified flow sheet of an existing Pyrobustor-facility in ARA Pustertal

3. Theoretical modelling

Measurements regarding the amount of generated coke and pyrolysis gas, respectively the composition of the generated coke and pyrolysis gas in accordance with the amount and composition of fed sewage sludge are due to the constructive design of the Pyrobustor facility and process conditions not practicable.

The below presented theoretical modelling has as target to fill out this gap. At its basis is standing the data collected from the existing Pyrobustor facility in Italy.

From the available information and information from literature it was attempted to derive a representative composition of the treated sewage sludge (SS). The challenge was to decide for representative organic compounds from the many possible contained substances. As representative organic compounds for the theoretical modelling of the process, cellulose and linolenic acid were chosen. The table below comprises the composition used in the mass and energy balance calculations:

Table 1: Model composition chosen for the theoretical calculations

	Composition DM wt %		**Composition SS** wt %	
Organic	55		49.5	
	$C_6H_{10}O_5$	$C_{18}H_{30}O_2$	$C_6H_{10}O_5$	$C_{18}H_{30}O_2$
	41.3	13.7	37.2	12.3
N_2	5		4.5	
P_2O_5	6		5.4	
S	0.5		0.5	
Cl	0.2		0.2	
Inert	33.3		30	
Water	-		10	

The heating value of the processed sludge was detected in the lab.

Figure 5 is showing the values collected from the facility in Italy:

- Amount of sewage sludge processed through the Pyrobustor,
- Operation temperature of the pyrolysis zone: 300 to 350 °C,
- Operation temperature of the oxidation zone: 620 to 650 °C,
- Temperature of the pyrolysis gas,
- The energy added to the unit,
- The surface losses of the Pyrobustor and PCC.

Figure 6 is showing the process parameters that are absolutely necessary for the modelling but they cannot be measured:

- Amount and energy content of the pyrolysis gases,
- Amount end energy content of the pyrolysis cokes.

The required amount of oxidation air could be measured principally; however the local boundary conditions do not allow the installation of the measurement devices.

The first unknown parameter to be defined is the amount of exhaust gas generated by the oxidation of the coke in the combustion drum.

Being given that the amount of additional natural gas and the respective air consumption is known, the amount of exhaust gas can be calculated from the simple formula:

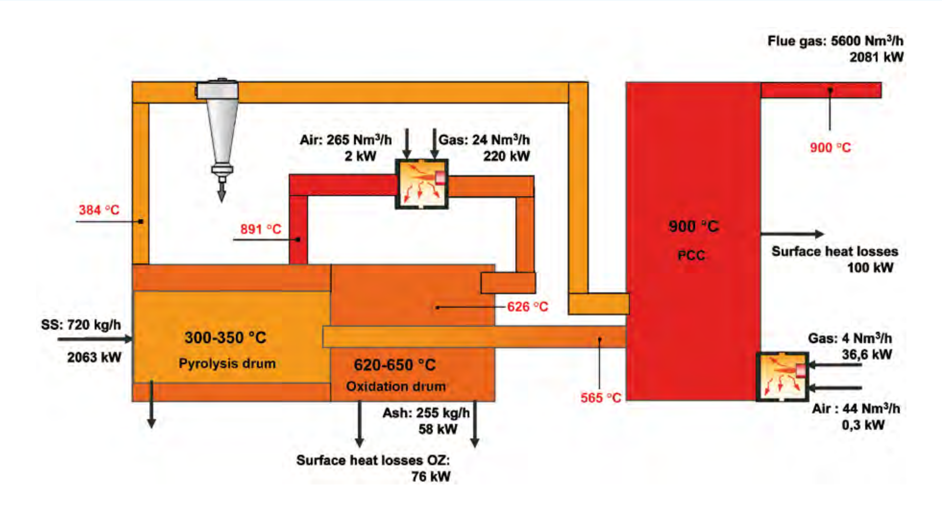

Figure 5: Summary of the known process parameters based on the recorded data of the plant in South Tyrol

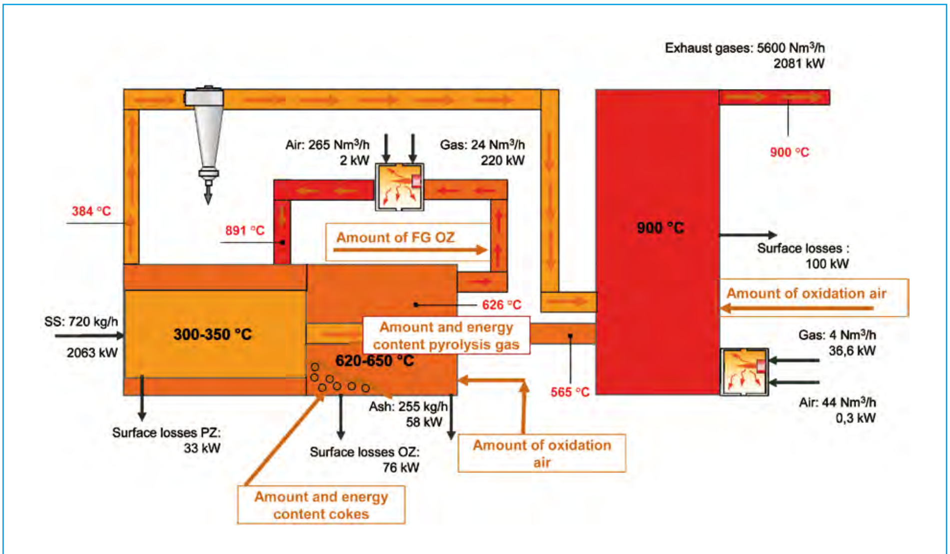

Figure 6: Summary of the unknown process parameters based on the recorded data of the plant in South Tyrol

$$\Delta Q = m \cdot Cp \cdot \Delta\delta \qquad m -_{OxiRG} = \frac{\Delta Q}{Cp \cdot \Delta\delta}$$

With the assumption of complete oxidation and the above calculated exhaust gas amount, the required oxidation amount can be iteratively defined.

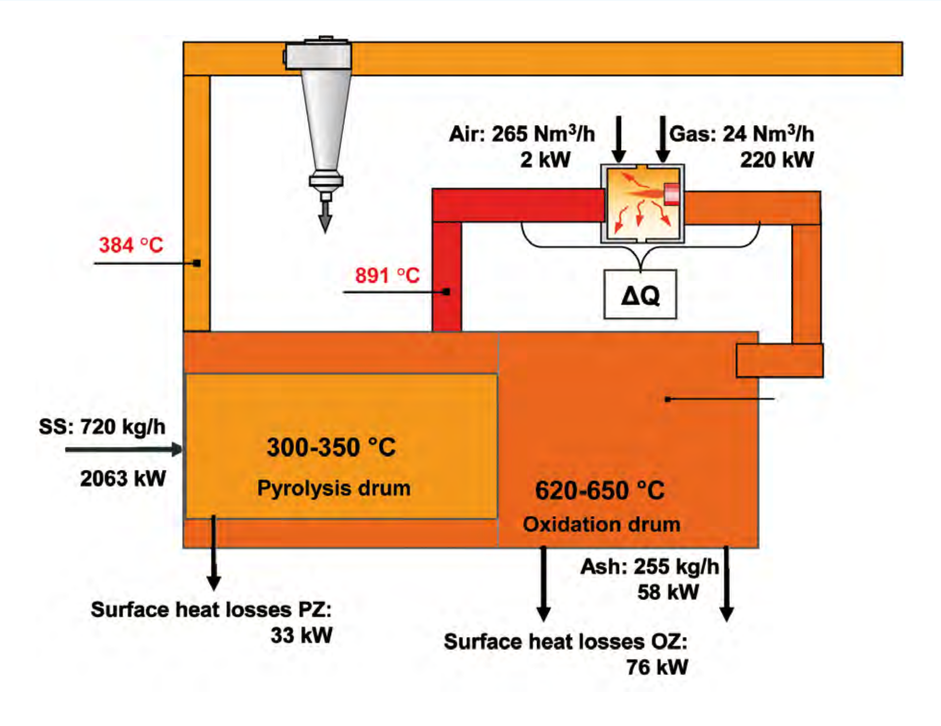

Figure 7: Determination of the exhaust gas amount ex oxidation zone

The amount of exhaust gas generated in the oxidation zone being known, the rest of unknowns can be defined by simply shifting the balance point for energy and mass equilibrium.

By setting the balance point around the Pyrobustor, the amount of generated pyrolysis gas can be calculated:

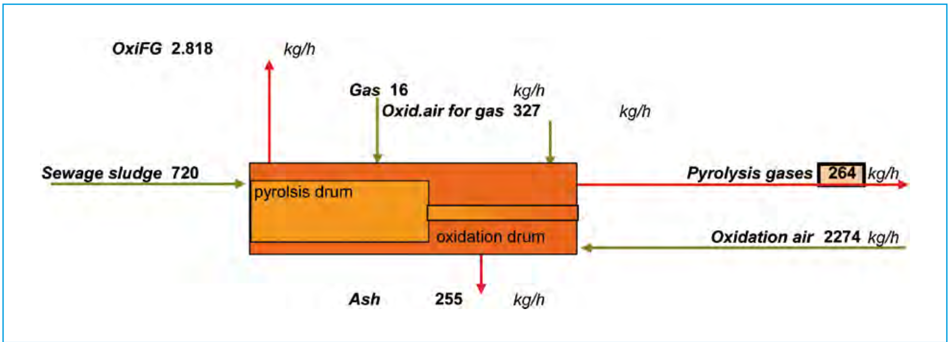

Figure 8: Mass balance Pyrobustor

The pyrolysis gas amount being known, by shifting the mass balance to the pyrolysis zone, the amount of generated coke can be deducted:

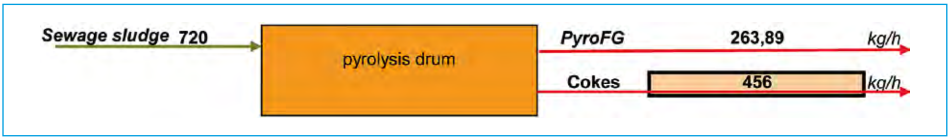

Figure 9: Mass balance pyrolysis zone

The exhaust gases leaving the Pyrobustor are directed to a cyclone for particulate matter removal. Downstream the cyclone the post combustion chamber is installed, where exhaust gases from the oxidation zone and pyrolysis gases from the pyrolysis zone are afterburned. The energy demand of the afterburning process is covered by the energy content of the pyrolysis gases. Thus, it is known that this energy amount is enough to heat up the known amount of exhaust gases entering the post combustion chamber to the operation temperature of the post combustion of about 900 °C as well the amount of required oxidation air in the PCC, so that the generated gases will have an oxygen content of 11 vol %. The amount of energy that is entering the system through the burner will be subtracted

This approach is summarized in the following equations:

$$Q_{PyroRG} = m_{OxiRG} \cdot \overline{Cp}\Big|_{384\,°C}^{900\,°C} \cdot \Delta\delta_{(900-384\,°C)} + M_{Oxid.\,air} \cdot \overline{Cp}\Big|_{20\,°C}^{900\,°C} \cdot \Delta\delta_{(900-20\,°C)} +$$

$$Q_{Surface\text{-}losses} - Q_{External\_heat}$$

Thus the heating value of the pyrolysis gases can be defined, having known the heat content of the gases from the above presented calculation and the amount of gases from the mass balance of the Pyrobustor:

$$Q_{PG} = m_{PG} \cdot Hu_{PG} \longrightarrow Hu_{PG} = \frac{Q_{PG}}{m_{PG}}$$

The fact that in case of only a slight decrease of temperature at the pyrolysis gas pipeline a significant amount of tar condensate is deposited, is an evidence that beside the typical pyrolysis products as CO, CO_2, CH_4, H_2 and a smaller amount of short chained carbohydrates, a significant amount of long chained carbohydrates are as well present.

Simultaneously, process defined, the water content of the input sludge is to be refound as well in the pyrolysis gas. Having these parameters defined, and having the heating value known, the composition of the pyrolysis gas can be approximated as summarized in Table 2:

Table 2: Iteratively defined pyrolysis gas composition

Compund	Pyrolysis gas			
	vol %	kmol/h	kg/h	wt %
CH_4	12	1	19	7
H_2O	40	4	72	27
CO_2	10	1	43	16
CO	24	2	67	25
H_2	5	0	1	0
C_2H_4	4	0	12	4
$C_xH_yO_z$	5	1	50	19

Based on this composition, the amount of required combustion air for the oxidation of the pyrolysis gas can de defined according to the respective stoichiometry.

As a next step, by placing the energy balance at the pyrolysis chamber, the energy content of the generated coke can be defined.

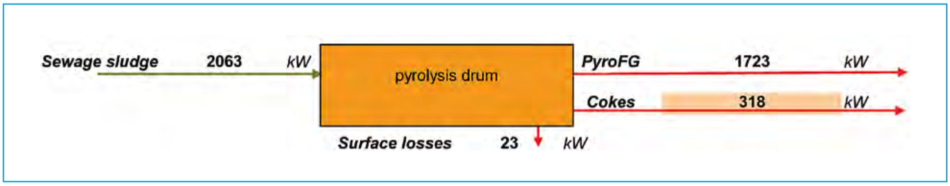

Figure 10: Energy balance pyrolysis zone

Thus all unknown parameter could be defined by iterative calculations and approximations. The results of these determinations are presented for the whole incineration unit in Figure 11 and Figure 12 as a global mass, respectively energy balance.

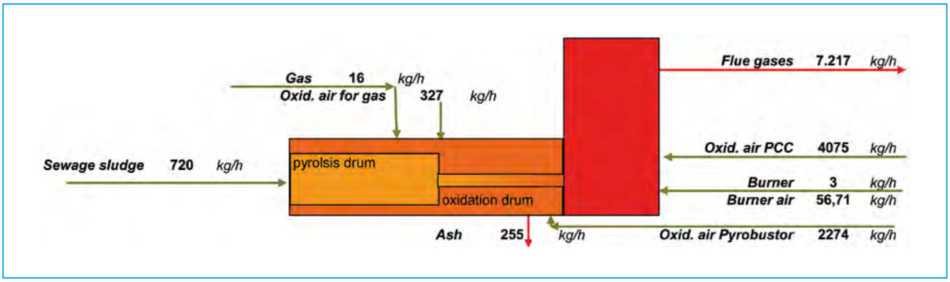

Figure 11: Global mass balance

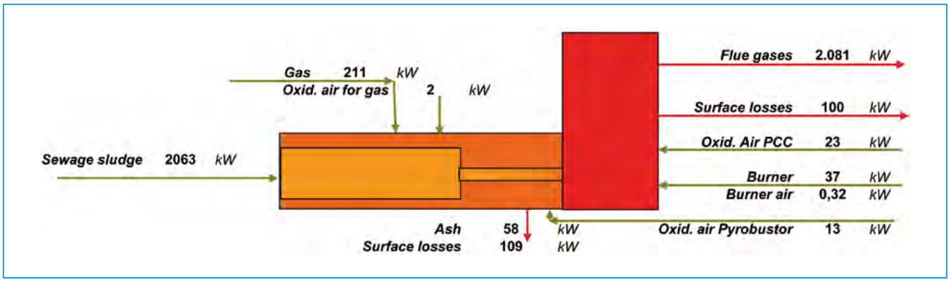

Figure 12: Global energy balance

In the above presented calculations it could be shown that based on the measurements from an existing Pyrobustor plant, all process parameters could be defined with the help of the theoretical modelling.

The physical and chemical properties of sewage sludge vary significantly according the generating source, applied waste water treatment system, location as well as season. The theoretical modelling now allows the tailor suited design of the Pyrobustor according to the sewage sludge to be processed.

4. Practical examples

The waste water treatment plant (WWTP), ARA Pustertal AG, is located approximately 70 km to the south from Brenner Pass, with a drainage area of about 1,150 km², serving 14 municipalities and a population equivalent of 450,000. The picture below shows the ARA Pustertal drainage area.

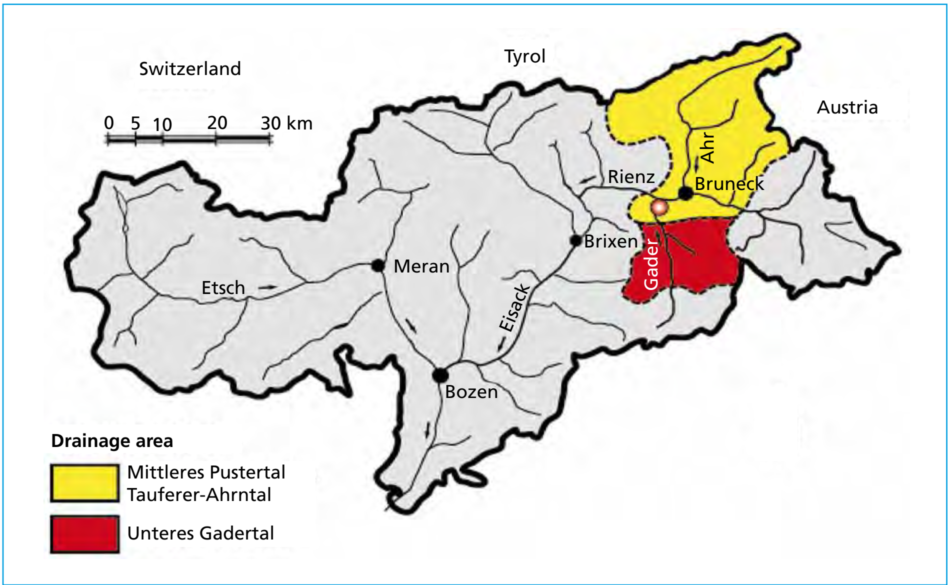

Figure 13: Drainage area of the ARA Pustertal AG

Source: Engl Konrad, The History of Thermal Waste Recycling at ARA Tobl

ARA Pustertal AG had been transporting its sewage sludge from the waste water treatment plant to the 300 km far away Po Valley for disposal. In search for more cost effective solutions, ARA Pustertal AG started an idea competition in 2003. The Pyrobustor presented by Eisenmann convinced the jury, so that in 2004 Eisenmann won the competition and was contracted for the thermal disposal of 550 kg/h dried sewage sludge, with a dry matter content of 90 %.

The plant was taken into operation in 2005 and had as battery limit the dried sewage sludge generated by the existing drier at waste water treatment plant, thus the scope of supply of Eisenmann comprises the incineration facility with the respective exhaust gas treatment system.

The incineration facility made itself attractive through the exploitation of the energy content of the exhaust gases leaving the post combustion chamber; energy that is returned to the existing sewage sludge drying system provided by the customer, thus having a nearly energy autarky system.

The particularity of the facility is that being located in a very touristic region, the public didn’t accept an open WWTP, therefore it had been decided to build it fully into the tunnel at the foot of the mountain Tobl. The drying unit and the thermal treatment facility with the respective exhaust gas treatment are located in the building at the foot of the mountain, upstream the tunnel (marked with red).

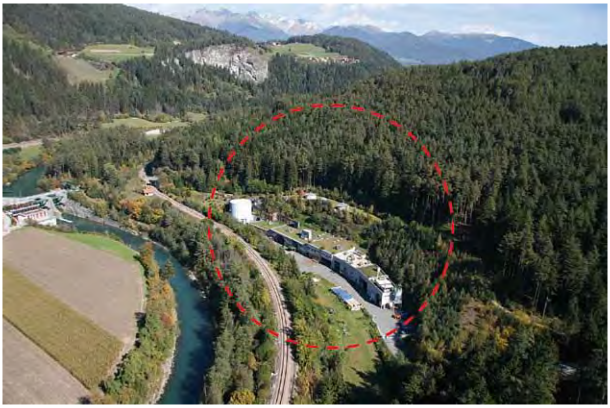

Figure 14:

WWTP with the respective thermal treatment facility in Pustertal, South Tyrol

Being located in an important recreation area, the compliance with emission limits has an increased importance. The Table 3 below comprises the emission limits to be fulfilled as well as the real emission values of the Pyrobustor facility, offering a fast overview about the efficiency of thermal conversion and exhaust gas treatment unit.

Table 3: Confrontation of emission limits in act with actual emission values

Parameter	Type	Emission limits mg/Nm³	Overage mg/Nm³
CO	online	50	2.20
NO_X	online	200/400	148
PM	online	10/30	3.10
C total	online	10/20	0.3
SO_2	online	50/200	41
HF	In situ	1/4	0.5
HCl	In situ	10/60	3
Dioxine-Furane	In situ	0.1 ng I-TE/Nm³	0.005 ng I-TE/Nm³
PAK	In situ	0.01 mg/Nm³	< 0.001 mg/Nm³

Source: Engl Konrad, The History of Thermal Waste Recycling at ARA Tobl

Due to the close cooperation between Eisenmann and the operator of the facility, the plant has been continuously optimized, so that an increase in throughput of nearly 24 % could be achieved, which leads to an availability of the thermal treatment unit of above 95 %. Simultaneously the following advantages are to be named:

- Long term independency in disposal availability,
- Saving of about 2,200 tonns of CO_2 per year,
- 311,000 km transportation costs per year.

In 2007 Eisenmann was contracted by the German KSV GmbH to build the second Pyrobustor in Crailsheim. The capacity of the plant is slightly above the initial throughput of the Pustertal plant, of 650 kg/h.

The picture below shows the Pyrobustor in the commissioning phase:

Figure 15:

Pyrobustor in Dinkelsbühl during commissioning

5. Sewage sludge and incineration in Poland

Poland is a significant contributor to the European sewage sludge generation, with an annual production of about 908 thousand tonnes of dry solids in 2009 [2]. While Germany is leading the European list with about 61 kg/capita, Poland has a production of approximately 37 kg/capita [3]. The available data regarding sewage sludge generation respectively sewage sludge disposal in Poland is not complete, which makes a full analysis difficult, however the tendencies in these directions can be still followed.

Regarding municipal sewage sludge generation a tendency of increased yearly production can be identified, as shown in Figure 16.

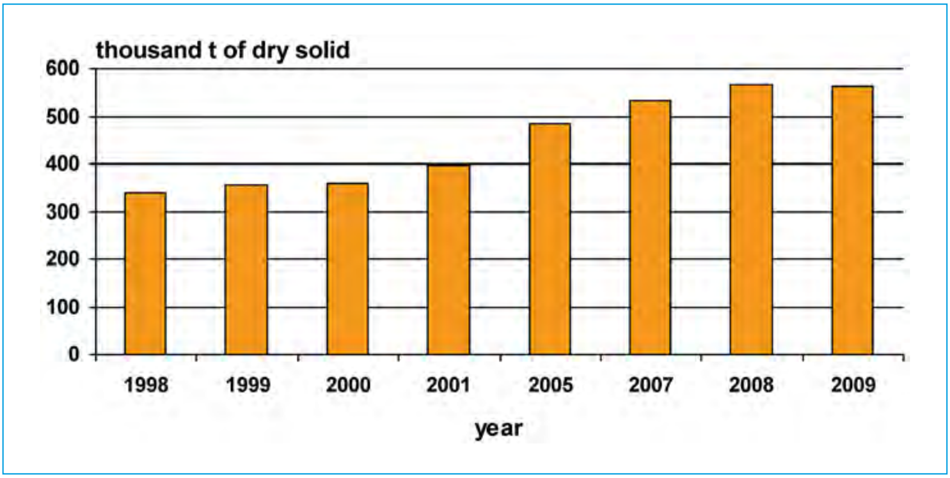

Figure 16: Sewage sludge amount from municipal WWTP [2, 5]

In case of industrial sewage sludge the trend is the opposite, a decrease of the generated yearly amount can be recognized according to Figure 17.

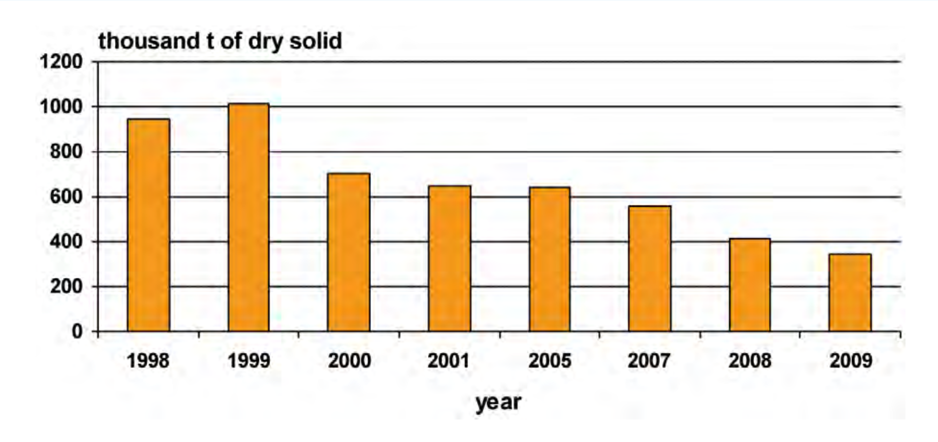

Figure 17: Sewage sludge amount from industrial WWTP

Sources:

GUS Central Statistical Office, Warsaw, 2010

Przewrocki, Risk Analysis of Sewage Sludge-Poland and EU Comparative Approach, Polish Journal of Environmental Studies, Vol. 13, No. 2, 237-244, 2004

As an overall balance a slight inclination towards reducing the total amount of sewage sludge generated by municipal as well as industrial WWTP is shown by Figure 18.

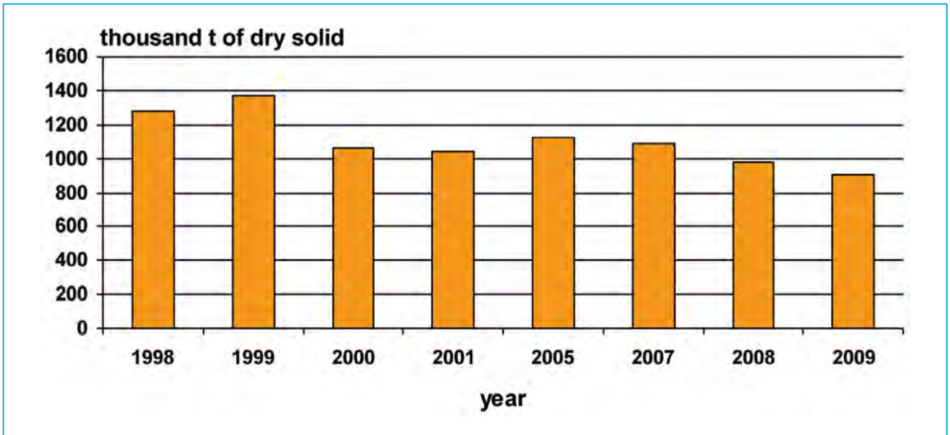

Figure 18: Total sewage sludge amount from WWTP

Sources:

GUS Central Statistical Office, Warsaw, 2010

Przewrocki, Risk Analysis of Sewage Sludge-Poland and EU Comparative Approach, Polish Journal of Environmental Studies, Vol. 13, No. 2, 237-244, 2004

In 2003 it was forecasted that the amount of municipal sewage sludge will be doubled by 2015. Poland set targets of limiting the amount of landfilled municipal sewage sludge, while increasing the proportion of thermally disposed sewage sludge up to 5 % by 2010 and further on to 8 % by 2015 [5].

According to the graphics from below, Poland reduced the amount of landfilled municipal sewage sludge significantly, but regarding to the portion of incinerated sludge no change can be identified, while the amount of landspreaded sewage sludge gained obvious proportions.

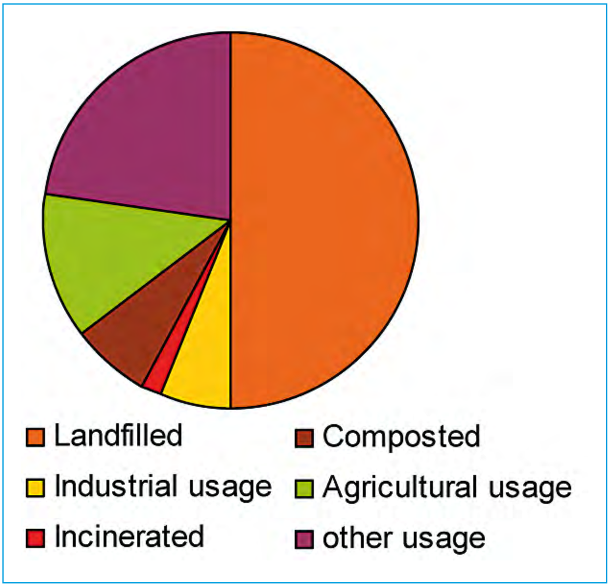

Figure 19:

Disposal of municipal sewage sludge in Poland, 2001

Source: Przewrocki, Risk Analysis of Sewage Sludge-Poland and EU Comparative Approach, Polish Journal of Environmental Studies, Vol. 13, No. 2, 237-244, 2004

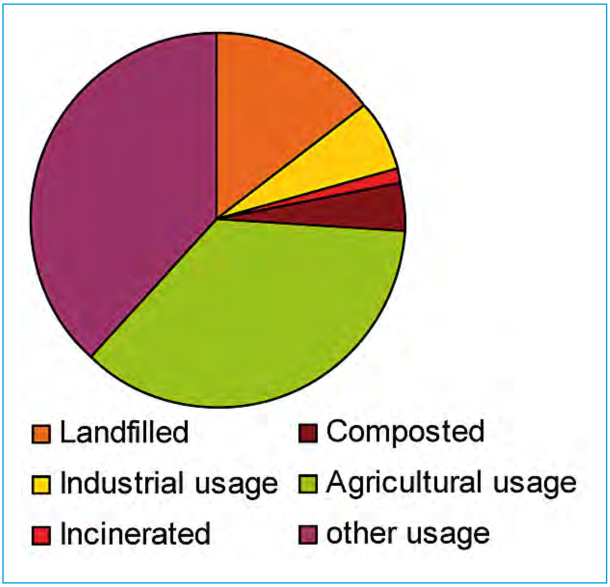

Figure 20:

Disposal of municipal sewage sludge in Poland, 2009

Source: GUS Central Statistical Office, Warsaw, 2010

Another unreckoned value not represented in the graphs above, is the amount of sludge accumulated at the end of the year 2009 at the waste water treatment plants. For industrial WWTP this value is in the height of 6,318 thousand of tons of dry matter, while for municipal WWTP it is significantly lower, 454 thousands of tons of dry matter [2].

The numbers presented above show a definite need for urgent measures for disposing of the impressive amount of sewage sludge accumulated. Due to the higher proportion of possible pollutants in the industrial sewage sludge the main way of disposal practiced in 2009, agricultural application is excluded. In order to meet the target of 8 % of the annually generated municipal sewage sludge to be incinerated, Poland must make new investments in the direction of thermal treatment of sewage sludge.

6. Summary and outlook

The Pyrobustor from Eisenmann offers a decentralized solution for smaller industrial and municipal waste water treatment plants for a throughput between 400-800 kg/h of dry matter.

The successful operation over the years of the Pyrobustor plant in Italy proves the high efficiency of the technology and confirms the cost-effectiveness of the process.

The presented theoretical modelling is a very helpful tool in the accurate design of the Pyrobustor and exhaust treatment, allowing to develop tailor-suited solutions according to varying requirements.

While the Pyrobustor technology is designed to make also smaller sewage sludge incineration plants attractive from the economical point of view, Eisenmann also offers the well established fluidized bed technology as central solution for the thermal treatment of both municipal and industrial sewage sludge.

7. Literature

[1] Thomé-Kozmiensky, Klärschlammentsorgung, Neuruppin, 1998

[2] GUS Central Statistical Office, Warsaw, 2010

[3] OEDC Environmental Data Compendium 1999, Paris, 1999

[4] Engl Konrad, The History of Thermal Waste Recycling at ARA Tobl

[5] Przewrocki, Risk Analysis of Sewage Sludge-Poland and EU Comparative Approach, Polish Journal of Environmental Studies, Vol. 13, No. 2, 237-244, 2004